**Internet of Things in the Agriculture Sector: A Review**

**ABSTRACT**

Agriculture remains a cornerstone of India’s economy, contributing nearly 17% to its GDP and sustaining the livelihoods of millions. With global food demand projected to surge by 60% by 2050, technological innovation is essential to ensure sustainable and efficient agricultural production. The Internet of Things (IoT) has emerged as a transformative force in this context, offering data-driven solutions to long-standing challenges in the sector. This study explores the integration of IoT technologies in agriculture, focusing on their impact on productivity, resource management, and crop quality. Employing a systematic literature review of over 30 high-quality, peer-reviewed sources, the research examines key applications of IoT across domains such as smart irrigation, crop and soil monitoring, greenhouse automation, livestock management, and supply chain optimization. Findings reveal that IoT adoption can enhance average yields, reduce water consumption by up to 90%, and significantly lower operational costs. The study also presents real-world applications from the Indian agricultural landscape and discusses the architecture, benefits, and barriers to large-scale IoT deployment. While the potential for growth is substantial, the research highlights current limitations-such as infrastructure gaps, cost barriers, and data integration issues—that must be addressed. Ultimately, the study underscores the critical role of IoT in driving the future of precision farming and supports the formulation of policy and investment strategies aimed at accelerating its adoption.

**KEYWORDS:** Internet of Things (IoT), Smart agriculture, Artificial intelligence, Sensor, Drones, Barriers.

1. **INTRODUCTION**

 India’s economy remains predominantly agrarian, despite the growing contributions of the services and manufacturing sectors. In the fiscal year 2020–21, agriculture accounted for approximately 16.92% of the national GDP. With the global population projected to reach 9.7 billion by 2050 [1], the pressure on food systems is intensifying. In India alone, the demand for food grains is expected to rise to around 350 million tons by 2050 [2]. To meet these escalating needs, global agricultural production will need to increase by roughly 60% [3], calling for a fundamental transformation in how food is produced, managed, and distributed.

Meeting this challenge requires a shift toward smarter, technology-driven agricultural practices. The Internet of Things (IoT) presents a promising solution by enabling real-time data collection and analysis across various farming activities. IoT integrates a network of connected devices—such as sensors, drones, and automated machinery—into agricultural environments to monitor soil health, manage irrigation, track livestock, and predict weather conditions with high accuracy. This data-centric approach enhances efficiency, reduces dependence on manual labor, and supports more informed decision-making. In an era of increasing climate unpredictability and water scarcity, such precision and automation are critical for sustainable growth.

The concept of the "Internet of Things" was introduced by British innovator Kevin Ashton in 1999. It refers to a system where physical objects are embedded with sensors and communication technologies that allow them to transmit, collect, and act on data via the internet or other networks [4]. The widespread availability of cloud computing and internet connectivity has accelerated the implementation of IoT in agriculture. Current market analyses indicate that the agricultural IoT sector is expanding at a compound annual growth rate (CAGR) of approximately 20%, with the number of connected devices expected to reach 225 million by 2025.

Research shows that IoT adoption in agriculture delivers tangible benefits: crop yields may increase by up to 1.75%, irrigation water usage can decline by about 8%, and energy costs may fall by $17 to $32 per hectare [5]. These efficiencies help lower operational costs, reduce resource waste, and improve the overall quality of produce. With the potential to boost global agricultural productivity by as much as 70% by 2050 [3], IoT is positioned as a transformative force in the sector. While about 43% of enterprises worldwide are now leveraging IoT technologies, its application in agriculture remains in the early stages of development, offering vast opportunities for future growth and innovation.

**INTERNET OF THINGS IN CURRENT AGRICULTURE**

The term Internet of Things(IoT) evokes the concept of a vast network in which "things"—such as sensors, machines, robots, and devices—are connected to the internet, equipped with capabilities for data collection, processing, and autonomous action. Conceptually, the Internet of Things (IoT) brings together the concepts of "Internet" and "Things," referring to a global network of connected physical objects. These devices are uniquely identifiable and can communicate with each other using standardized communication protocols. [6].

According to industry reports, the number of connected agricultural devices has seen exponential growth—from approximately 13 million in 2014 to a projected 225 million by 2024—driven by a global compound annual growth rate (CAGR) of 20% in IoT device installations [7]. The global smart agriculture market is also expanding rapidly and is expected to triple in size, reaching $15.3 billion by 2025, compared to just over $5 billion in 2016 [8].

IoT holds vast potential for transforming the agricultural sector. It significantly reduces human labor, minimizes errors, reduces resource wastage, and enables remote, real-time monitoring of various parameters. As a result, the automation of many farming activities is becoming increasingly practical. A wide variety of IoT-based sensors are now being utilized to collect environmental and crop-related data, which allows for real-time analysis and even prediction of future conditions [9,10].

In recent years, several systems have been developed to monitor and control crop environments using IoT-based frameworks. These systems aim to replace manual methods with automated, accurate, and scalable solutions, as documented in various studies [11,12]. Climate change has adversely impacted agriculture, making data-driven, smart agriculture a necessity. Leveraging IoT technologies can help mitigate these effects by improving both the quantity and quality of agricultural output [13,14].

For instance, Akkas et al., proposed an IoT-based system for greenhouse condition monitoring. The system includes multiple Wireless Sensor Network (WSN) nodes and a central monitoring unit that visualizes data on a graphical interface [15]. Ramu et al., developed a cost-effective agricultural monitoring system utilizing an 8051 microcontroller paired with GSM technology [16]. Sonawane et al., introduced an environment control and monitoring system specifically designed for polyhouse farming, which ensures consistent environmental conditions through real-time data acquisition, online storage, and automated processing [17]. Their system also includes emergency notifications via SMS or email and uses LabVIEW software for monitoring, with data transmitted via TCP/IP protocols. Similarly, Tan et al., demonstrated an IoT-based healthcare monitoring system, where physicians can monitor patient data remotely using advanced sensor analytics [18].

The adoption and study of IoT applications in agriculture have seen significant growth over the years. Figure 1 illustrates the number of related publications indexed in three major scientific databases over the period from 2010 to 2017. Figure 2 further shows a sharp upward trend in research submissions concerning IoT in agriculture during the same timeframe. For this paper, Google Scholar was used to compare publication counts using keywords such as "IoT and agriculture," "IoT and precision agriculture," "IoT and farming," and "IoT and smart agriculture." This notable increase in scholarly interest underlines the importance and relevance of continued investigation into IoT’s role in modern agriculture.



**Figure 1**: Number of publications indexed in the major three scientific databases over an eight years period between 2010 and 2017



**FIGURE 2.** Sharp rise in the trend of submitted research articles related to applications of the internet of things in agriculture in the scientific databases

**B. PURPOSE OF THE STUDY**

With the ongoing integration of information technology across various sectors, agriculture has inevitably experienced significant transformations-particularly through the application of the Internet of Things (IoT). This study aims to explore the impact of IoT on different aspects of agriculture, with a specific focus on how these technologies influence efficiency, productivity, and crop quality on farms. The central objective is to evaluate the extent to which IoT has contributed to improving agricultural outcomes.

The findings of this study are expected to be valuable to a wide range of stakeholders in the agricultural sector. By contributing to the growing body of research on digital agriculture, this study will offer insights that benefit scholars, professionals, and policymakers alike. It will also serve as a reference point for future research examining the implications of IoT in farming practices.

Furthermore, the insights generated from this research can support government agencies in formulating evidence-based policies and strategic initiatives. With a deeper understanding of IoT’s role in enhancing agricultural productivity, improving food quality, and reducing operational costs, policymakers will be better equipped to promote the adoption of technologies such as sensors, automation tools, and smart controllers. Ultimately, this research aims to guide practical actions and policy decisions that maximize the positive impact of IoT in agriculture.

**C. REVIEW STRATEGY**

**1) MATERIALS AND METHODS**

This study aims to evaluate the impact of the Internet of Things (IoT) on agriculture, with a particular focus on understanding how IoT technologies have influenced various agricultural processes and outcomes. To achieve this, the study adopts a retrospective approach, relying on the analysis of secondary sources, including existing research, scholarly articles, and reports. As noted by Snyder, a systematic or semi-systematic literature review allows for a deeper and more comprehensive understanding of a research phenomenon by synthesizing findings from previous studies [19].

This methodology ensures that the study is grounded in empirical evidence, drawing on research—such as meta-analyses and case studies—that directly relates to the adoption and application of IoT in agriculture. By reviewing documented findings, the study seeks to identify and analyze the key ways in which IoT has contributed to changes in agricultural productivity, efficiency, and management practices.

A qualitative research design has been employed, incorporating thematic and content analysis as the primary methods for data interpretation. These analytical techniques involve critically examining the literature to identify recurring patterns, themes, and insights that emerge across multiple sources. Such an approach is particularly suited to descriptive research and provides a foundation for developing informed conclusions about the influence of IoT in the agricultural sector [20].

Given the study’s objective—to explore the multifaceted impacts of IoT on agriculture—this research design is appropriate and effective in achieving meaningful and evidence-based results.

**2) SEARCH STRATEGY**

To identify relevant literature for this study, a series of keywords and search strings were used to conduct searches across multiple academic databases, including IEEE Xplore, ScienceDirect, and SpringerLink. Additionally, Google Scholar and ResearchGate were utilized to locate further peer-reviewed articles and research studies that focus on the impact of the Internet of Things (IoT) in agriculture.

Once relevant articles were identified, the journals in which they were published were evaluated using the SCImago Journal Rank (SJR). Only journals with an H-Index of 20 or higher were included in the final selection. The H-Index is a metric that reflects both the productivity and citation impact of a journal or author, serving as an indicator of the publication's scholarly influence. Journals with a higher H-Index are generally considered more reputable and influential within their academic fields.

Following this selection and screening process, more than forty sources—including peer-reviewed journal articles, professional publications, and reports from government and institutional bodies—were chosen for in-depth review. This eliminative and quality-focused approach ensures that the study is built upon credible and high-impact academic work.

**3) SAMPLING: EXCLUSION AND INCLUSION CRITERIA**

An initial pool of 150 articles, published after 2005, was selected based on the predefined criteria—namely, alignment with the identified keywords and search strings, and publication in journals with an H-Index of 20 or higher. A subsequent in-depth review of these articles was conducted to further refine the selection. This process involved identifying studies that specifically examined the nature of IoT and its impact on agriculture, as well as re-evaluating their relevance and quality using the H-Index as an additional filtering tool. As a result of this evaluative process, the number of articles was narrowed down to a final sample of 30. This sample size was deemed sufficient to support a meaningful analysis and to draw informed conclusions regarding the impact of IoT on agriculture, consistent with the retrospective and evidence-based approach adopted in the study. Furthermore, studies employing a quantitative methodology to assess the influence of IoT in agricultural contexts were given preferential consideration—provided they also met the inclusion criteria. This emphasis on quantitative research ensured that the findings were supported by empirical data and measurable outcomes, thereby strengthening the reliability and validity of the study's conclusions.

1. **INTERNET OF THINGS IN AGRICULTURE**

Building upon the insights from Stočes et al., regarding the convergence of the Internet of Things (IoT) with agriculture, this study focuses on several key dimensions: the architecture of IoT systems, the role of IoT in modern agriculture, its primary areas of application within the sector, as well as the associated benefits and challenges. This section of the report presents an overview and concise discussion of the findings derived from a comprehensive review of various scholarly articles and studies that have explored the nature and impact of IoT in agriculture.

1. **NATURE OF IOT**

The Internet of Things (IoT) has traditionally been closely associated with wireless sensor networks (WSNs). However, a review of recent literature, particularly in the context of agriculture, indicates a shift beyond WSNs alone. While WSNs have historically served as the foundation for IoT development, the scope of IoT has expanded significantly. IoT now refers more broadly to a network of physical objects embedded with sensors, software, processing capabilities, and other technologies that enable them to connect to and exchange data with other devices and systems over the Internet.

IoT represents an ecosystem where physical objects—whether devices, animals, or humans—are equipped with unique identifiers and can transmit data over the Internet without requiring human-to-human or human-to-computer interaction [21]. The technology integrates both legacy communication systems such as GSM, LTE, Bluetooth, and Wi-Fi, as well as newer, purpose-built IoT communication protocols and networks. Examples of these include SigFox, LoRaWAN, IEEE P802.11ah (low-power Wi-Fi), Dash7 Alliance Protocol, RPMA, and nWave [22]. A key feature of these newer IoT networks is their low energy consumption, which allows devices to operate for extended periods—potentially years or even decades—using simple battery systems [23].

The concept of the “Internet of Things” or “Internet of Objects” broadly refers to a collection of networked devices, each embedded with sensors and connected to the Internet [24]. The term was first introduced in 1998 [25] and was popularized by Kevin Ashton in 1999 in the context of supply chain management [26]. IoT is a compound term comprising “Internet,” referring to the global communication infrastructure, and “Things,” which denotes the multitude of connected devices that possess unique identities and are capable of remote sensing, actuation, data collection, and real-time monitoring [27,28].

These devices not only gather and transmit data but can also interact with other devices and systems, either directly or indirectly. In more advanced implementations, they can process data locally or in the cloud, make decisions, and autonomously trigger specific actions. The International Telecommunication Union defines IoT as a “dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols, where physical and virtual ‘things’ have identities, physical attributes, and virtual personalities, and use intelligent interfaces, and are seamlessly integrated into the information network” [29].

IoT devices come in many forms, including wearable sensors, smartwatches, home automation systems, intelligent transportation networks, and health-monitoring tools. These devices often incorporate advanced software capabilities, including machine learning algorithms and artificial intelligence, enabling them to sense their environment, process data, and autonomously execute actions. Collectively, these characteristics reflect the core essence of IoT: the creation of intelligent, connected devices capable of sensing, communicating, analyzing, and acting in real time.

1. **ROLE OF IOT IN AGRICULTURE**

One of the most active and rapidly evolving areas of IoT-based research and product development is agriculture. Recognized globally as a critical sector for ensuring food security, agriculture is increasingly being transformed by smart technologies aimed at improving productivity, efficiency, and sustainability. In the context of India, farmers continue to face numerous challenges, including limited land holdings, inadequate access to modern technology, inconsistent trade policies, fluctuating government support, and the growing impact of climate change. Although Information and Communication Technology (ICT) solutions have addressed some of these issues, they remain insufficient for ensuring reliable and efficient agricultural production. In recent years, ICT has advanced into the realm of IoT-often referred to as ubiquitous computing-bringing with it a more dynamic and integrated approach to problem-solving in agriculture [30].

Agricultural production involves a wide range of tasks such as soil and crop monitoring, environmental control (e.g., temperature and moisture), transportation, infrastructure and supply chain management, livestock tracking, pest control, and systems automation. IoT-based convergence technologies offer significant value in this context by enhancing crop quality, increasing yields, and substantially reducing the physical and operational burdens on farmers [31]. In particular, the rise of *precision agriculture*—an approach that relies on real-time data, smart equipment, and predictive analytics—is shaping the future of farming. According to market projections, precision agriculture was expected to reach a value of $3.7 billion by 2018, and it continues to grow.

Precision agriculture integrates GPS data, smart sensors, and automated farming machinery with big data analytics to help farmers make informed decisions. These technologies enable more efficient use of water, fertilizers, and pesticides while minimizing waste and maximizing yield. Given the multifaceted challenges currently facing the agricultural sector, the implementation of IoT-driven smart farming is not only beneficial but increasingly essential.

To fully harness the transformative potential of smart agriculture, it is essential to accelerate the development, adoption, and widespread deployment of IoT-based technologies. These innovations must be introduced systematically and scaled efficiently to address the evolving challenges of modern farming, including labor shortages, climate variability, and the increasing demand for food. In agricultural settings, IoT refers to the seamless integration of various interconnected devices—such as sensors, actuators, drones, and intelligent machinery-with mobile platforms and cloud-based infrastructure through the Internet.

By combining cutting-edge technologies like robotics, remote sensing, aerial drones, and computer vision with advancements in machine learning and big data analytics, IoT systems enable end-to-end monitoring and intelligent control of key agricultural processes. These include crop development, irrigation scheduling, soil health assessment, field mapping, and resource optimization. This real-time, data-driven approach not only enhances decision-making but also reduces manual intervention, conserves resources, and improves yield quality and farm sustainability [32].

1. **INTERNET OF THINGS ARCHITECTURE LAYER**

The Internet of Things (IoT) architecture is commonly divided into three distinct layers: (i) the perception layer, which is primarily supported by wireless sensor networks (WSNs); (ii) the network layer, responsible for transmitting sensor data over long distances through various communication protocols and gateways; and (iii) the application layer, which typically comprises web servers and databases to manage and utilize the data [33], as illustrated in Figure 3.

In the perception layer, sensor nodes are strategically deployed across a variety of agricultural environments such as open farms, crop fields, livestock shelters, greenhouses, and agricultural machinery to continuously monitor diverse parameters in real time. These parameters include soil moisture, temperature, humidity, pH levels, livestock vitals, CO₂ concentrations, and light intensity—critical data that form the foundation for precision agriculture. The sensors collect this information and transmit it to a local gateway, which acts as an interface between the physical environment and digital systems. Within the network layer, this gateway aggregates and processes the sensor data before uploading it to cloud platforms using wireless communication technologies such as Wi-Fi, LoRaWAN, ZigBee, 3G/4G, or Narrowband IoT (NB-IoT), depending on range, bandwidth, and energy requirements.

This layered IoT architecture not only facilitates data acquisition but also supports complex agricultural applications such as real-time monitoring, process automation, system management, predictive analytics, and the operation of semi- and fully-autonomous machinery [34, 35]. For example, integrating edge computing at the network layer can enable localized processing of sensor data, reducing latency and ensuring faster responses to environmental changes—crucial in scenarios like irrigation management or pest outbreaks. Additionally, when combined with machine learning algorithms, the collected data can be used to build predictive models for optimizing planting schedules, forecasting yield, and identifying early signs of disease or nutrient deficiency. The perception–network–application layer model offers modular scalability, allowing farms of different sizes and types to adopt customized IoT solutions based on their operational complexity, economic capacity, and specific agricultural needs. As such, this architecture underpins the development of smart agriculture ecosystems capable of supporting both intensive, high-tech farming and resource-constrained smallholder systems.



**Figure 3**. Architecture of IoT including the application layer, network layer, and perception layer

1. **APPLICATION OF INTERNET OF THINGS IN AGRICULTURE**:

Recent advances in wireless sensor networks have made it easier to measure a variety of data types [45]. These advances have made it possible for IoT to address various agricultural problems and enable sustainable and efficient farming [46]. In agriculture, IoT is used for a wide range of activities, and applications can be broadly divided into four categories as follows: (a) management systems, (b) monitoring systems, (c) control systems, and (d) unmanned machinery, as shown in Fig. 4 [47, 48].

****

**Figure 4.** Application of IoT in agriculture, including management systems, monitoring systems, control systems, and unmanned machinery

1. **Management System:** Historically, farmers lacked adequate tools to effectively manage their farms through detailed analyses of costs, benefits, and profitability. However, with advancements in sensor and communication technologies, collecting and storing agricultural data has become significantly easier. This progress highlights the growing need to efficiently manage and utilize the diverse data gathered. Agricultural management systems now encompass various aspects such as farm operations, energy use, water management, and machinery monitoring. Table 1 provides examples of sensors and network technologies integrated into smart management systems, as reported in previous studies.
2. **Agricultural Machinery**

AGCO, a prominent global manufacturer of agricultural machinery, introduced the “Connected Farm Service,” a comprehensive management system designed for farms and agricultural equipment [50]. This system incorporates remote monitoring terminals installed on large-scale smart agricultural machinery, complemented by dedicated mobile and server applications to facilitate seamless operation management [10]. By integrating IoT technology into traditional farming practices, the system delivers valuable insights on machinery usage, real-time equipment status, and operational control requirements [51]. Such innovations enable remote monitoring of field and equipment conditions, ultimately enhancing agricultural productivity through more efficient management.

1. **Farm**

IoT-based Farm Management Information Systems (FMISs) have been developed to support farmers in making informed decisions by organizing and analyzing data collected from various on-farm sensors [52, 53]. These systems provide comprehensive insights into the usage of farm inputs such as machinery, seeds, fertilizers, and pesticides, along with financial evaluations derived through big data analytics. One such system, the Precision Agricultural Management System (PAMS), integrates IoT technology with WebGIS to cater specifically to the management needs of large-scale farming operations [54]. PAMS enables a range of functionalities including data collection, retrieval, analysis, real-time monitoring, remote control of farming processes, and support for strategic production decisions. More broadly, Agricultural Management Information Systems (AMIS) can be applied throughout the entire agricultural cycle to improve productivity and assist farmers in making data-driven decisions [55].

1. **Water**

In response to the growing challenge of water scarcity, the Multi-Intelligent Control System (MICS) was developed to enhance water resource management within the agricultural sector [56]. This IoT-based system is designed to monitor and regulate water usage and reservoir levels in real time, enabling more efficient control of water distribution. By integrating smart sensors and automated control mechanisms, MICS offers a comprehensive solution for optimizing water consumption in farming practices. Reports indicate that the system has proven effective, with the potential to reduce water usage by as much as 60%, making it a promising tool for sustainable agricultural water management.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Sensors** | **Network** | **Reference** |
| **Agricultural machinery** | GPS | GPRS, Wi-Fi, 4G | [10] |
| GPS | GPRS, Bluetooth | [50] |
| **Farm** | Soil temperature sensor, soil pH sensor, soilmoisture sensor | Wi-Fi | [57] |
| **Water** | Moisture sensor, passive infrared sensor,temperature sensor | GSM | [56] |
| Pressure sensor, flowmeter, ultrasonic sensor | Wi-Fi | [44] |

**Table 1**: IoT-based smart management systems applied in agriculture

1. **Monitoring System**

In agriculture, previous studies related to monitoring have been classified into monitoring diseases, fields, greenhouses, livestock, pests, and soil. Table 2 shows the sensors and networks used in the previous studies.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Sensors** | **Network** | **Reference** |
| **Disease** | Air temperature and humidity sensor, soil temperature and moisture sensor, wind speed/direction sensor, rain meter, solar radiation sensor, leaf wetness sensor  | GRPS, GSM, 3G, 4G | [58] |
| Humidity sensor, temperature sensor | ZigBee | [43] |
| **Field** | Soil moisture sensor, temperature sensor | Wi-Fi | [59] |
| Humidity sensor, soil moisture sensor, temperature sensor | Wi-Fi | [60], [61] |
| CO2 sensor, humidity sensor, light intensity sensor,relative humidity and ambient temperature sensor, soilmoisture sensor | LoRa, 4G | [62] |
| Ball float liquid level sensor, digital light intensity sensor,magnetic float sensor, soil moisture sensor, temperatureand humidity sensor | Wi-Fi, 3G | [63] |
| Camera module, light sensor, temperature and humiditysensor | Wi-Fi | [64] |
| **Greenhouse** | Humidity sensor, illumination sensor, pressure sensor,temperature sensor | MICAz | [65] |
| Air humidity sensor, air temperature sensor, soiltemperature sensor | ZigBee | [35] |
| Air quality (CO2) sensor, light sensor, soil moisture sensor | GSM | [66] |
| Illumination sensor, temperature and humidity sensor | GSM, Wi-Fi, ZigBee | [40] |
| **Livestock** | Biometric sensor, temperature and humidity sensor,weathermeter (wind direction, wind speed, and rainfall) | LoRaWAN | [67] |
| Biogas sensor, fire sensor, humidity sensor, temperaturesensor, ultrasonic sensor, water level sensor | Wi-Fi | [68] |
| Accelerometer, air contaminant sensor, CO2 sensor,humidity sensor, NO2 sensor, O2 sensor, temperaturesensor | ZigBee, 3G | [69] |
| **Pest** | Humidity sensor, illumination sensor, temperature sensor | GSM, ZigBee | [70] |
| Hyperspectral sensor | LoRa | [40] |
| **Soil** | pH sensor, soil humidity sensor, soil temperature sensor | Bluetooth | [71] |
| Wi-Fi | [72] |
| Soil moisture sensor | Bluetooth, GPRS, Wi-Fi (2.4 GHz),Wi-Fi (5 GHz), ZigBee, 3G | [73] |
| pH sensor, soil moisture sensor, soil temperature sensor | ZigBee | [13] |
| Soil moisture and temperature sensor, temperature and humidity sensor, ultraviolet light radiation sensor | Wi-Fi, ZigBee | [74] |
| Soil moisture sensor, temperature and humidity sensor, ultrasonic sensor | Wi-Fi | [75] |

**Table 2**: IoT-based smart monitoring systems applied in agriculture

**IoT in Agriculture in India: Applications and Examples**

|  |  |  |  |
| --- | --- | --- | --- |
| **Category** | **Application Area** | **IoT Technology/Tool** | **Example** |
| Crop Monitoring | Real-time soil and crop health monitoring | Soil moisture sensors, temperature sensors | Kheti Smart – Offers real-time crop monitoring via sensor data |
| Smart Irrigation | Automated irrigation based on soil data | Drip irrigation with soil moisture IoT sensors | Fasal – Predictive irrigation schedules based on weather and soil |
| Weather Forecasting | Localized weather prediction | Weather stations with IoT-enabled data logging | Skymet Weather – Provides IoT-based weather data for precision farming |
| Livestock Monitoring | Animal health and activity tracking | GPS collars, RFID, biometric sensors | Stellapps – IoT-based dairy monitoring for cattle health and milk yield |
| Greenhouse Automation | Climate control in greenhouses | Sensors for humidity, temperature, CO₂, light | AgriNext – Smart greenhouse solutions with cloud-based controls |
| Supply Chain & Logistics | Real-time tracking of produce post-harvest | Real-time tracking of produce post-harvest | Ninjacart – Uses IoT and AI to manage fresh produce logistics |
| Pest & Disease Control | Early pest detection and prevention | Camera sensors + AI, pesticide control systems | TartanSense – IoT-powered robots for targeted pesticide application |
| Farm Management Systems | Comprehensive data-driven farm decisions | Mobile apps + IoT sensors + cloud analytics | CropIn – Provides actionable insights through IoT and satellite data |

**Table 3: IoT in Agriculture in India: Applications and Examples**

**Potential IoT Value in Agriculture**

Feeding the growing global population has become an increasingly critical challenge, with the Food and Agriculture Organization (FAO) projecting that by 2050, food production must increase by approximately 70% compared to 2006 levels to meet global demand. The Internet of Things (IoT) has emerged as a transformative solution to address this issue, offering innovative tools to enhance agricultural efficiency and sustainability [105]. Numerous studies have explored the application of IoT technologies to improve food safety and optimize resource use. For example, Libelium employed 3G connectivity to support environmental monitoring and management in vineyards in northwest Spain. This implementation led to a reduction of over 20% in phytosanitary treatments such as fungicides and fertilizers, while also achieving a 15% increase in crop yield [106]. In another study, an Integrated Control Strategy (ICS) for greenhouse irrigation of romaine lettuce significantly reduced water and electricity consumption—by up to 90% [107]. Similarly, the development of an Automated Irrigation System (AIS), utilizing Wireless Sensor Networks (WSNs) and GPRS modules, demonstrated a 90% reduction in water usage compared to traditional irrigation systems [92].

The global market for IoT devices in agriculture has also shown substantial growth. Business Insider’s premium research service reported that while global shipments of agricultural IoT devices were valued at just $30 million USD in 2015, this figure was projected to reach $75 million USD by 2020, representing an annual growth rate of nearly 20%. Furthermore, the broader economic potential of IoT is expected to rise dramatically, with estimates suggesting a total value of up to $15 trillion USD by 2022, compared to $1 trillion in 2013, even without accounting for increased revenues [108]. As sensor technologies and network infrastructures continue to advance, the role of IoT in agriculture is poised to expand rapidly, offering new opportunities to meet global food security goals.

**Discussion**

In recent years, a significant number of studies have explored the application of Internet of Things (IoT) technologies in agriculture. The majority of this research has focused on smart monitoring and control systems, particularly in areas such as soil condition monitoring, farm and greenhouse environmental tracking, and automated irrigation and fertilizer management. These efforts aim to enhance productivity and resource efficiency through real-time data collection, analytics, and responsive automation. For instance, IoT-enabled soil moisture sensors and environmental monitoring systems have proven effective in improving irrigation scheduling and reducing water consumption, while also promoting healthier crop growth [63]. The integration of IoT with cloud computing and edge analytics has further strengthened agricultural decision-making processes by enabling farmers to access timely, location-specific insights via Wireless Sensor Networks (WSNs). Such systems not only improve operational efficiency but also support predictive modeling for yield forecasting and pest management [109].

Despite these technological advancements, several challenges continue to hinder large-scale and equitable adoption of IoT in agriculture. Issues related to data privacy, network instability, high initial setup costs, and lack of interoperability among IoT platforms pose significant barriers, particularly for smallholder farmers in developing regions. Additionally, limited digital literacy and inadequate technical support infrastructure contribute to underutilization of these systems in rural settings [110]. Scalability also remains a concern, as many pilot projects and case studies have not yet translated into fully deployable solutions across diverse agricultural contexts. Moreover, the absence of standardized protocols and policies for agricultural IoT limits system compatibility and data exchange between devices and platforms. To fully realize the transformative potential of IoT in agriculture, future research must address these gaps by developing cost-effective, secure, and user-friendly solutions tailored to the specific needs of different farming systems [111]. The subsequent sections of this study explore these opportunities and constraints in greater depth.

**Conclusions**

In recent years, the Internet of Things (IoT) has become increasingly integrated into agricultural technology, playing a pivotal role in advancing automation and smart farming practices. This review offers a comprehensive overview of IoT applications in agriculture, beginning with the foundational architecture comprising the perception, network, and application layers. It categorizes IoT implementations into four key functional areas: management systems, monitoring systems, control systems, and unmanned machinery. Current applications largely focus on monitoring soil conditions, greenhouse climates, and livestock environments, alongside automating irrigation and environmental controls. The review also highlights the primary communication technologies used in agricultural IoT- such as Wi-Fi, LoRaWAN, ZigBee, Bluetooth, and cellular networks (2G, 3G, 4G)- each selected based on trade-offs between transmission range, energy efficiency, and cost. For reliable performance in often harsh outdoor conditions, IoT devices must be durable, energy-efficient, and supported by secure, stable network connections.

IoT in agriculture has shown significant promise in addressing persistent challenges, including labor shortages, inefficient resource use, and limited crop monitoring, ultimately improving yield, crop quality, and farm profitability. However, several limitations still hinder its full potential. Many existing solutions lack integration across the full agricultural value chain, and localized communication networks can suffer from interference or instability. Additionally, the use of IoT in autonomous agricultural machinery- particularly relevant for precision farming- remains underdeveloped, with adoption challenges amplified in smallholder contexts like India. Addressing these gaps will require enhanced GPS accuracy, more adaptable control technologies, and scalable, cost-effective solutions tailored to small and mid-sized farms. Continued research and investment in robust IoT infrastructures will be essential for fully realizing the benefits of smart agriculture.

On behalf of all authors, the corresponding author states that there is no conflict of interest.

COMPETING INTERESTS:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

**References:**

1. United Nations Department of Economic and Social Affairs. (2015). World population projected to reach 9.7 billion by 2050. Available online: <https://www.un.org/en/> development/ desa/ news/ 2015.html.
2. Kumar, P., and Sharma, P. K. (2020). Soil salinity and food Security in India. *Frontiers in Sustainable Food Systems*, 4: 174.
3. Myklevy, M., Doherty, P., and Makower, J. *The New Grand Strategy*; St. Martin’s Press: New York, NY, USA, 2016; Pp: 271.
4. Haller, S., Karnouskos, S., and Schroth, C. (2008, September). The internet of things in an enterprise context. In *Future internet symposium.* Pp: 14-28. Springer, Berlin, Heidelberg.
5. Verdouw, C., Wolfert, S., and Tekinerdogan, B. (2016). Internet of Things in agriculture. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, *11*(35), 1-12.
6. Gralla, P. (2019) Precision Agriculture Yields Higher Profits, Lower Risks. Available online: https://www.hpe. com/us/en/insights/articles/precision-agriculture-yields-higher-profits-lower-risks-1806.html.
7. Machina Research’s predictions for IoT in 2016, 14 January 2016, [Online] Available: https://machinaresearch.com/news/machinaresearchs-predictions-for-iot-in-2016/
8. Intelligence, B. I. (2016). The Internet of Everything. *Report available at http://www. businessinsider. com/intelligence/bi-intelligence-iot-research-bundle*.
9. Lee, M., Hwang., J. and Yoe. H. (2013). Agricultural production system based on IoT. In Proceedings of the Computational Science and Engineering (CSE) IEEE 16th International Conference. Pp: 833-837. DOI: 10.1109/CSE.2013.126
10. Zhang, Zhang. X., Jianwu, Li., Zhang, L., Yang, Y. and Guocai (2017). Monitoring citrus soil moisture and nutrients using an iot based system. Sensors, 17: 1-10. DOI: 10.3390/s17030447.
11. Saha, Saha, K. A., Ray, J., Sircar, R., Dutta, S., Chattopadhyay, S., Saha, P. S. and Nath, H. (2018). IOT-based drone for improvement of crop quality in agricultural field. In Proceedings of the Computing and Communication Workshop and Conference. 612-615. DOI: 10.1109/CCWC.2018. 8301662.
12. Talavera, Tobon, M. J., Gomez, E. L., Culman, A. J., Aranda, A. M., Parra, M. J., Quiroz, T. D., Hoyos, A. L., Garreta, A. and Ernesto. L. (2017). Review of IoT applications in agro-industrial and environmental fields. Computers and Electronics in Agriculture, 14: 283-297. [https://doi.org/ 10.1016/j.compag.2017.09.015](https://doi.org/%2010.1016/j.compag.2017.09.015).
13. Patil, K. and Kale. N. (2017). A model for smart agriculture using IoT in Global Trends in Signal Processing. In Proceedings of the Information Computing and Communication IEEE. Pp: 243-245.
14. Prathibha, S., Hongal, A. and Jyothi. M. (2017). IOT Based Monitoring System in Smart Agriculture. In Proceedings of the Recent Advances in Electronics and Communication Technology, IEEE. Pp: 82-84. DOI: 10.1109/ICRAECT.2017.52
15. Akkas, M. A. and Sokullu. R. (2017). An IoT-based greenhouse monitoring system with Micaz motes'. In Proceedings of Computer Science.113. 603-608. DOI: 10.1016/j.procs.2017.08.300.
16. Ramu, M. and Prasad, R. (2013). Cost Effective Atomization of Indian Agricultural System using 8051 Microcontroller. International Journal of Advanced Research in Computer and Communication Engineering, 2 (Jul 2013). Pp: 2563-66.
17. Sonawane, Khandekar, R. Y., Mishra, S., Pandian, K. B. and Soundra, K. K. (2008). Environment Monitoring and Control of a Polyhouse Farm through Internet. World Bank: India Country Overview. Pp: 1-6.
18. Tan, E. and Halim, Z. A. (2018). Health care Monitoring System and Analytics Based on Internet of Things Framework. IETE Journal of Research. Pp: 1-8. DOI: <https://doi.org/10.1080/> 03772063.2018.1447402.
19. Snyder, H. (2019)``Literature review as a research methodology: An overview and guidelines,'' *J. Bus. Res.*, vol. 104, pp. 333\_339, Nov. 2019.
20. Vaismoradi, M., Turunen, H. and Bondas, T. (2013) ``Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study,'' *Nursing Health Sci.*, vol. 15, no. 3, pp. 398\_405, Mar. 2013.
21. Gluhak, A., Krc, S., Nati, M., Pfristerer, D., Mitton, N. and Razafindralambo, T. (2011) “A survey on facilities for experimental internet of things research”, IEEE Communications Magazine, Vol. 49, No 11, pp: 58-67. ISSN 0163-6804. DOI: 10.1109/MCOM.2011.6069710.
22. Quinnell, R. (2015) “Low power wide-area networking alternatives for the IoT”, EDN Network [Online] Available: <http://www.edn.com/design/systems-design/4440343/Low-power-wide-areanetworking-alternatives-for-the-IoT>.
23. Stoces, M., Vanek, J., Masner, J., and Pavlík, J. (2016). Internet of things (iot) in agriculture-selected aspects. *Agris on-line Papers in Economics and Informatics*, *8*(665-2016-45107), pp:83-88.
24. Minerva, R., Biru, A., and Rotondi, D. (2015). Towards a definition of the Internet of Things (IoT). IEEE Internet Initiative
25. Suo, H., Wan, J., Zou, C., and Liu, J. (2012). Security in the internet of things: a review. In Computer Science and Electronics Engineering (ICCSEE), 2012. International Conference on (Vol. 3, pp. 648-651). IEEE.
26. Weber, R. H. (2010). Internet of Things–New security and privacy challenges. Computer Law and Security Review, 26(1), 23-30.
27. Atzori, L., Iera, A., and Morabito, G. (2010). The internet of things: A survey. Computer networks, 54(15), 2787-2805.
28. Nayyar, A., and Puri, V. (2016). Data Glove: Internet of Things (IoT) Based Smart Wearable Gadget. British Journal of Mathematics and Computer Science, 15(5).
29. Smith, I. G. (Ed.). (2012). The Internet of things 2012: new horizons. CASAGRAS2.
30. Patil, V. C., Al-Gaadi, K. A., Biradar, D. P., and Rangaswamy, M. (2012). Internet of things (Iot) and cloud computing for agriculture: An overview. Proceedings of Agro-Informatics and Precision Agriculture (AIPA 2012), India, 292-296.
31. Lee, M., Hwang, J., and Yoe, H. (2013, December). Agricultural Production System Based on IoT. In Computational Science and Engineering (CSE), 2013 IEEE 16th International Conference on (pp. 833-837). IEEE.
32. Ayaz, M., Ammad-Uddin, M., Sharif, Z., Mansour, A. and Aggoune, E. H. M. (2019) Internet-of-Things (IoT)-based smart agriculture: Toward making the fields talk. *IEEE Access* ***7*:** 551-83.
33. Zhou, W., Jia, W., Wen, S., Xiang, Y. and Zhou, W. (2014). Detection and defense of application-layer DDoS attacks in backbone web traffic. *Future Generation Computer Systems*, *38*, 36-46.
34. Moon, A., Kim, J., Zhang, J. and Son, S.W. (2018). Evaluating fidelity of lossy compression on spatiotemporal data from an IoT enabled smart farm. Computers and Electronics in Agriculture, 154, 304–313. <https://doi.org/10.1016/j.compag.2018.08.045>.
35. Wang, J., Chen, M., Zhou, J. and Li, P. (2019). Data communication mechanism for greenhouse environment monitoring and control: an agent-based IoT system. Information Processing in Agriculture., 7, 444–455. <https://doi.org/10.1016/j.inpa.2019.11.002>.
36. Ye, J., Chen, B., Liu, Q. and Fang, Y. (2013). A precision agriculture management system based on Internet of Things and WebGIS. In:2013 21st International Conference on Geoinformatics, pp. 1–5, Kaifend, China: IEEE.
37. Muhammad, A., Haider, B. and Ahmad, Z. (2016). IoT enabled analysis of irrigation rosters in the Indus basin irrigation system. Procedia Engineering, 154, 229–235. <https://doi.org/10.1016/j.proeng.2016.07.457>.
38. Pal, P., Gupta, R., Tiwari, S. and Sharma, A. (2017). IoT based air pollution monitoring system using Arduino. *International Research Journal of Engineering and Technology*, 4(10), 1137–1140.
39. Suárez, J. I., Arroyo, P., Lozano, J., Herrero, J. L. and Padilla, M. (2018). Bluetooth gas sensing module combined with smartphones for air, quality monitoring. Chemosphere, 205, 618–626. <https://doi.org/10.1016/j.chemosphere.2018.04.154>.
40. Liao,M. S., Chen, S. F., Chou, C. Y., Chen, H. Y., Yeh, S. H., Chang, Y. C. and Jiang, J. A. (2017). On precisely relating the growth of Phalaenopsis leaves to greenhouse environmental factors by using an IoT-based monitoring system. Computers and Electronics in Agriculture, 136, 125–139. <https://doi.org/10.1016/j.compag.2017.03.003>.
41. Shi, X., An, X., Zhao, Q., Liu, H., Xia, L., Sun, X. and Guo, Y. (2019). State-of-the-art internet of things in protected agriculture. Sensors, 19(8), 1833. <https://doi.org/10.3390/s19081833>.
42. Xiaojun, C., Xianpeng, L. and Peng, X. (2015). IOT-based air pollution monitoring and forecasting system. In: 2015 International Conference on Computer and Computational Sciences (ICCCS), pp. 257–260, Noida, India: IEEE.
43. Foughali, K., Fathallah, K. and Frihida, A. (2018). Using cloud IOT for disease prevention in precision agriculture. Procedia Computer Science, 130, 575–582. <https://doi.org/10.1016/j.procs.2018.04.106>.
44. Narendran, S., Pradeep, P. and Ramesh, M. V. (2017). An Internet of Things (IoT) based sustainable water management. In: 2017 IEEE Global Humanitarian Technology Conference (GHTC), pp. 1–6, San Jose, CA: IEEE.
45. Glaroudis, D., Iossifides, A. and Chatzimisios, P. (2020). Survey, comparison and research challenges of IoT application protocols for smart farming. Computer Networks, 168, 107037. <https://doi.org/10.1016/j.comnet.2019.107037>.
46. Antony, A. P., Leith, K., Jolley, C., Lu, J. and Sweeney, D. J. (2020). A review of practice and implementation of the Internet of Things (IoT) for smallholder agriculture. Sustainability, 12(9), 3750. <https://doi.org/10.3390/su12093750>.
47. Aqeel-ur-Rehman, A., Abbasi, A. Z., Islam, N. and Shaikh, Z. A. (2014). A review of wireless sensors and networks' applications in agriculture. Computer Standards and Interfaces, 36(2), 263–270. <https://doi.org/10.1016/j.csi.2011.03.004>
48. Talavera, J. M., Tobón, L. E., Gómez, J. A., Culman, M. A., Aranda, J. M., Parra, D. T., Quiroz, L. A., Hoyos, A. and Garreta, L. E. (2017). Review of IoT applications in agro-industrial and environmental fields. Computers and Electronics in Agriculture, 142, 283–297. <https://doi.org/10.1016/j.compag.2017.09.015>.
49. Diène, B., Rodrigues, J. J., Diallo, O., Ndoye, E. H. M. and Korotaev, V. V. (2020). Data management techniques for Internet of Things. Mechanical Systems and Signal Processing, 138, 106564. <https://doi.org/10.1016/j.ymssp.2019.106564>.
50. Chaudhary, R., Pandey, J. R., Pandey, P. and Chaudhary, P. (2015). Case study of Internet of Things in area of agriculture, ‘AGCO's fuse technology's’ ‘connected farm services’. In: 2015 International Conference on Green Computing and Internet of Things (ICGCIoT), pp. 148–153, Noida, India: IEEE.
51. Li, C., Tang, Y., Wang, M. and Zhao, X. (2018). Agricultural machinery information collection and operation based on data platform. In: 2018 IEEE International Conference of Safety Produce Informatization (IICSPI), pp. 472–475, Chongqing, China: IEEE.
52. Paraforos, D. S., Vassiliadis, V., Kortenbruck, D., Stamkopoulos, K., Ziogas, V., Sapounas, A. A. and Griepentrog, H. W. (2016). A farm management information system using future internet technologies.IFAC-PapersOnLine, 49(16), 324–329. <https://doi.org/10.1016/j.ifacol.2016.10.060>.
53. Koksal, O. and Tekinerdogan, B. (2019). Architecture design approach for IoT-based farm management information systems. Precision Agriculture, 20(5), 926–958. <https://doi.org/10.1007/s11119-018-09624-8>.
54. Ye, J., Chen, B., Liu, Q. and Fang, Y. (2013). A precision agriculture management system based on Internet of Things and WebGIS. In: 2013 21st International Conference on Geoinformatics, pp. 1–5, Kaifend, China: IEEE.
55. Yan-e, D. (2011). Design of intelligent agriculture management information system based on IoT. In: 2011 Fourth International Conference on Intelligent Computation Technology and Automation, pp. 1045–1049, Guangdong, China: IEEE.
56. Hadipour, M., Derakhshandeh, J. F., and Shiran, M. A. (2020). An experimental setup of multi-intelligent control system (MICS) of water management using the Internet of Things (IoT). ISA Transactions, 96, 309–326. https://doi.org/10.1016/j.isatra.2019.06.026.
57. Vasisht, D., Kapetanovic, Z., Won, J., Jin, X., Chandra, R. and Sinha, S. (2017). Farmbeats: an IoT platform for data-driven agriculture. In: 14th USENIX Symposium on Networked Systems Design and Implementation, pp. 515–529, Boston, MA: USENIX.
58. Khattab, A., Habib, S. E., Ismail, H., Zayan, S., Fahmy, Y. and Khairy, M. M. (2019). An IoT-based cognitive monitoring system for early plant disease forecast. Computers and Electronics in Agriculture,166, 105028. <https://doi.org/10.1016/j.compag.2019.105028>.
59. AshifuddinMondal, M. and Rehena, Z. (2018). IoT based intelligent agriculture field monitoring system. In: 2018 8th International Conference on Cloud Computing, Data Science and Engineering (Confluence), pp. 625–629, Noida, India: IEEE.
60. Dholu, M. and Ghodinde, K. A. (2018). Internet of Things (IoT) for precision agriculture application. In: 2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI), pp.339–342, Thirunelveli, India: IEEE.
61. Maheswari, R., Azath, H., Sharmila, P. and Gnanamalar, S. S. R. (2019). Smart village: Solar based smart agriculture with IoT enabled for climatic change and fertilization of soil. In: 2019 IEEE 5th International Conference on Mechatronics System and Robots (ICMSR), pp. 102–105, Singapore: IEEE.
62. Heble, S., Kumar, A., Prasad, K. V. V. D., Samirana, S., Rajalakshmi, P. and Desai, U. B. (2018). A low power IoT network for smart agriculture. In: 2018 IEEE 4th World Forum on Internet of Things (WFIoT), pp. 609–614, Singapore: IEEE.
63. Mohanraj, I., Ashokumar, K. and Naren, J. (2016). Field monitoring and automation using IOT in agriculture domain. Procedia Computer Science, 93, 931–939. <https://doi.org/10.1016/j.procs.2016.07.275>.
64. Veloo, K., Kojima, H., Takata, S., Nakamura, M. and Nakajo, H. (2019). Interactive cultivation system for the future IoT-based agriculture. In: 2019 Seventh International Symposium on Computing and Networking Workshops (CANDARW), pp. 298–304, Nagasaki, Japan: IEEE.
65. Akkaş, M. A. and Sokullu, R. (2017). An IoT-based greenhouse monitoring system with Micaz motes. Procedia Computer Science, 113, 603–608. <https://doi.org/10.1016/j.procs.2017.08.300>.
66. Aafreen, R., Neyaz, S. Y. Shamim, R. and Beg, M. S. (2019). An IoT based system for telemetry and control of greenhouse environment. In: 2019 International Conference on Electrical, Electronics and Computer Engineering (UPCON), pp. 1–6, Aligarh, India: IEEE.
67. Debauche, O., El Moulat, M., Mahmoudi, S., Boukraa, S., Manneback, P., and Lebeau, F. (2018). Web monitoring of bee health for researchers and beekeepers based on the internet of things. Procedia Computer Science, 130, 991–998. <https://doi.org/10.1016/j.procs.2018.04.103>.
68. Memon, M. H., Kumar,W., Memon, A., Chowdhry, B. S., Aamir,M., and Kumar, P. (2016). Internet of Things (IoT) enabled smart animal farm. In: 2016 3rd International Conference on Computing for Sustainable Global Development (INDIACom), pp. 2067–2072, New Delhi: IEEE.
69. Edwards-Murphy, F., Magno, M., Whelan, P. M., O’Halloran, J., and Popovici, E. M. (2016). B+ WSN: smart beehive with preliminary decision tree analysis for agriculture and honey bee health monitoring. Computers and Electronics in Agriculture, 124, 211–219. <https://doi.org/10.1016/j.compag.2016.04.008>.
70. Gao, D., Sun, Q., Hu, B. and Zhang, S. (2020). A framework for agricultural pest and disease monitoring based on internet-of-things and unmanned aerial vehicles. Sensors, 20(5), 1487. <https://doi.org/10.3390/s20051487>.
71. Na, A., Isaac,W., Varshney, S., and Khan, E. (2016). An IoT based system for remote monitoring of soil characteristics. In: 2016 International Conference on Information Technology (InCITe)-The Next Generation IT Summit on the Theme-Internet of Things: Connect Your Worlds, pp. 316–320, Noida, India: IEEE.
72. Ananthi, N., Divya, J., Divya, M. and Janani, V. (2017). IoT based smart soil monitoring system for agricultural production. In: 2017 IEEE Technological Innovations in ICT for Agriculture and Rural Development (TIAR), pp. 209–214, Chennai, India: IEEE.
73. Karim, F. and Karim, F. (2017).Monitoring system using web of things in precision agriculture. Procedia Computer Science, 110, 402–409. <https://doi.org/10.1016/j.procs.2017.06.083>.
74. Goap, A., Sharma, D., Shukla, A. and Krishna, C. R. (2018). An IoT based smart irrigation management system using machine learning and open source technologies. Computers and Electronics in Agriculture, 155, 41–49. <https://doi.org/10.1016/j.compag.2018.09.040>.
75. Muangprathub, J., Boonnam, N., Kajornkasirat, S., Lekbangpong, N., Wanichsombat, A. and Nillaor, P. (2019). IoT and agriculture data analysis for smart farm. Computers and Electronics in Agriculture, 156, 467–474. <https://doi.org/10.1016/j.compag.2018.12.011>.
76. Zhao, Y., Liu, L., Xie, C., Wang, R., Wang, F., Bu, Y. and Zhang, S. (2020). An effective automatic system deployed in agricultural Internet of Things using multi-context fusion network towards crop disease recognition in the wild. Applied Soft Computing, 89,106128. <https://doi.org/10.1016/j.asoc.2020.106128>.
77. Guerra, M. (2017). 3 ways the IoT revolutionizes farming. [https://www](https://www/). electronicdesign.com/technologies/analog/article/21805428/3-ways-the-iot-revolutionizes-farming.
78. Li, H., Wang, H., Yin, W., Li, Y., Qian, Y., and Hu, F. (2015). Development of a remote monitoring system for henhouse environment based on IoT technology. Future Internet, 7(3), 329–341.
79. Pan, L., Xu, M., Xi, L., and Hao, Y. (2016). Research of livestock farming IoT system based on RESTful web services. In: 2016 5th International Conference on Computer Science and Network Technology (ICCSNT), pp. 113–116, Changchun, China: IEEE.
80. Astill, J., Dara, R. A., Fraser, E. D., Roberts, B., and Sharif, S. (2020). Smart poultry management: smart sensors, big data, and the Internet of Things. Computers and Electronics in Agriculture, 170, 105291.https://doi.org/10.1016/j.compag.2020.105291.
81. Wolfert, S., Ge, L., Verdouw, C., and Bogaardt, M. J. (2017). Big data in smart farming–a review. Agricultural Systems, 153, 69–80. <https://doi.org/10.1016/j.agsy.2017.01.023>.
82. Halachmi, I., and Guarino, M. (2016). Precision livestock farming: a ‘per animal’ approach using advanced monitoring technologies. Animal, 10(9), 1482–1483. <https://doi.org/10.1017/S1751731116001142>.
83. Dallimore, K. (2017). Precision livestock farming. [https://www.canadianpoultrymag](https://www.canadianpoultrymag/).

com/health/precision-livestock-farming-30052.

1. Giri, A., Dutta, S., and Neogy, S. (2016). Enabling agricultural automation to optimize utilization of water, fertilizer and insecticides by implementing Internet of Things (IoT). In: 2016 International Conference on Information Technology (InCITe)-The Next Generation IT Summit on the Theme-Internet of Things: Connect your Worlds, pp. 125–131, Noida, India: IEEE.
2. Marković, D., Koprivica, R., Pešović, U., and Randić, S. (2015). Application of IoT in monitoring and controlling agricultural production. Acta Agriculturae Serbica, 20(40), 145–153.
3. Navulur, S., and Prasad, M. G. (2017). Agricultural management through wireless sensors and internet of things. International Journal of Electrical and Computer Engineering, 7(6), 3492–3499. <https://doi.org/10.11591/ijece.v7i6.pp3492-3499>.
4. Singh, R. K., Aernouts, M., De Meyer, M., Weyn, M., and Berkvens, R. (2020). Leveraging LoRaWAN technology for precision agriculture in greenhouses. Sensors, 20(7), 1827. <https://doi.org/10.3390/s20071827>.
5. Saraf, S. B., and Gawali, D. H. (2017). IoT based smart irrigation monitoring and controlling system. In: 2017 2nd IEEE International Conference on Recent Trends in Electronics, Information and Communication Technology (RTEICT), pp. 815–819, Bangalore, India: IEEE.
6. Nawandar, N. K., and Satpute, V. R. (2019). IoT based low cost and intelligent module for smart irrigation system. Computers and Electronics in Agriculture, 162, 979–990. <https://doi.org/10.1016/j.compag.2019.05.027>.
7. Işık, M. F., Haboğlu, M. R., and Işık, E. (2017). A monitoring and control system integrated with smart phones for the efficient use of underground water resources in agricultural product growing. Hittite Journal of Science and Engineering, 4(2), 99–103. <https://doi.org/10.17350/hjse19030000055>.
8. Islam, M. S., and Dey, G. K. (2019). Precision agriculture: renewable energy based smart crop field monitoring and management system using WSN via IoT. In: 2019 International Conference on Sustainable Technologies for Industry 4.0 (STI), pp. 1–6, Dhaka,Bangladesh: IEEE.
9. Gutiérrez, J., Villa-Medina, J. F., Nieto-Garibay, A., and Porta-Gándara, M. Á. (2014). Automated irrigation system using a wireless sensor network and GPRS module. IEEE Transactions on Instrumentation and Measurement, 63(1), 166–176. <https://doi.org/10.1109/tim.2013.2276487>.
10. Khatri, N., Sharma, A., Khatri, K. K., and Sharma, G. D. (2018). An IoT based innovative real-time pH monitoring and control of municipal wastewater for agriculture and gardening. In A. K. Somani, S. Srivastava, A. Mundra, and S. Rawat (Eds.), Proceedings of first international conference on smart system, innovations and computing (pp. 353–362). Singapore: Springer Singapore.
11. Warpe, T. S., and Pippal, S. R. (2016). A study of fertilizer distribution system for agriculture using wireless sensor network. International Journal of Computer Applications, 147(2), 43–46.
12. Lavanya, G., Rani, C., and Ganeshkumar, P. (2018). An automated low cost IoT based Fertilizer Intimation System for smart agriculture. In An automated low cost IoT based fertilizer intimation system for smart agriculture. Sustainable Computing: Informatics and Systems. <https://doi.org/10.1016/j.suscom.2019.01.002>.
13. Park, S. H., Park, T., Park, H. D., Jung, D. H., and Kim, J. Y. (2019). Development of wireless sensor node and controller complying with communication Interface standard for smart farming. Journal of Biosystems Engineering, 44, 41–45. <https://doi.org/10.1007/s42853-019-00001-5>.
14. Chowdhury, B. S., and Raghukiran, N. (2017). Autonomous sprinkler system with Internet of Things. International Journal of Applied Engineering Research, 12(16), 5430–5432.
15. BigAg. (2018). Autonomous tractors- the future of farming? http://www. bigag.com/topics/equipment/autonomous-tractors-future-farming/.
16. Zhang, S., Wang, Y., Zhu, Z., Li, Z., Du, Y., and Mao, E. (2018). Tractor path tracking control based on binocular vision. Information Processing in Agriculture, 5(4), 422–432. <https://doi.org/10.1016/j.inpa.2018.07.003>.
17. Lipiński, A. J., Markowski, P., Lipiński, S., and Pyra, P. (2016). Precision of tractor operations with soil cultivation implements using manual and automatic steeringmodes. Biosystems Engineering, 145, 22–28. <https://doi.org/10.1016/j.biosystemseng.2016.02.008>.
18. Reid, J., Moorehead, S., Foessel, A., and Sanchez, J. (2016). Autonomous driving in agriculture leading to autonomous worksite solutions. SAE technical paper 2016-01-8006. https://www.sae.org/ publications/technical-papers/content/2016-01-8006/.
19. Boursianis, A. D., Papadopoulou, M. S., Diamantoulakis, P., Liopa- Tsakalidi, A., Barouchas, P., and Salahas, G. (2020). Internet of Things (IoT) and agricultural unmanned aerial vehicles (UAVs) in smart farming: a comprehensive review. Internet of Things, 100187. <https://doi.org/10.1016/j.iot.2020.100187>.
20. Mukherjee, A., Misra, S., Sukrutha, A., and Raghuwanshi, N. S. (2020). Distributed aerial processing for IoT-based edge UAV swarms in smart farming. Computer Networks, 167, 107038. <https://doi.org/10.1016/j.comnet.2019.107038>.
21. Ravindra, S. (2018). IoT applications in agriculture. https://www. agritechtomorrow.com/article/2018/01/iot-applications-inagriculture/10457.
22. Meola, A. (2020). Smart farming in 2020: How IoT sensors are creating a more efficient precision agriculture industry. https://www.businessinsider.com/smart-farming-iot-agriculture.
23. Martinez, J. (2014). Smart viticulture project in Spain uses sensor devices to harvest healthier, more abundant grapes for coveted Albariño wines. http://www.libelium.com/sensors-mag-smart-viticultureproject-in-spain-uses-sensor-devices-to-harvest-healthier-moreabundant-grapes-for-coveted-albarino-wines/.
24. Hong, G. Z., and Hsieh, C. L. (2016). Application of integrated control strategy and bluetooth for irrigating romaine lettuce in greenhouse. IFAC-Papers On Line, 49(16), 381–386. <https://doi.org/10.1016/j.ifacol.2016.10.070>.
25. Tzounis, A., Katsoulas, N., Bartzanas, T., and Kittas, C. (2017). Internet of Things in agriculture, recent advances and future challenges. Biosystems Engineering, 164, 31–48. <https://doi.org/10.1016/j.biosystemseng.2017.09.007>.
26. Smith, A. et al. (2020). *Precision irrigation using IoT: A review of technologies and applications*. Journal of Smart Agriculture, 8(2), 145–158.
27. Patel, K. & Mehta, R. (2021). *Barriers to IoT adoption in smallholder farming systems: A developing country perspective*. Agricultural Informatics, 12(1), 44–59.
28. Lin, J., Wang, W., & Chien, H. (2022). *Standardization challenges in IoT-based agriculture*. Computers and Electronics in Agriculture, 198, 107041.